BEBR
FACULTY WORKING
PAPER NO. 90-1665

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July 1990

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The authors are respectively Professor of Economics, Ph.d. candidate in economics, and Professor of Economics. Brueckner and Spiller gratefully acknowledge support from the Institute of Government and Public Affairs and the Research Board at the University of Illinois. Spiller also acknowledges support from the W.B. McKinley Chair in Economics and Public Utilities and from the Lilly foundation, through the Center for the Study of the Economy and the State at the University of Chicago.

ABSTRACT

This paper studies the impact of network characteristics on airfares. Our central hypothesis is that any force that increases traffic volume on the spokes of a network will reduce fares in the markets that it serves. This effect arises because of increasing returns on the spokes. For example, since a large network (as measured by the number of city pairs that it connects) is expected to have low costs per passenger as a result of high traffic densities, fares in the individual markets served should be low, other things equal. Similarly, holding size fixed, a network that connects large cities should have higher traffic densities on its spokes (and thus lower fares in individual markets) than one serving small cities. Our empirical analysis supports that predictions. We find that network characteristics are important determinants of fares in 4-segment city-pair markets (these are markets requiring a connection at the hub). Furthermore, our empirical model predicts that the TWA-Ozark and Northwest-Republic mergers should have reduced fares in the 4-segment markets served by the hubs at St. Louis and Minneapolis.

Fare Determination in Airline Hub-and-Spoke Networks

by

Jan K. Brueckner, Nichola J. Dyer, and Pablo T. Spiller

1. Introduction

Airline deregulation has led to profound changes in the structure of the industry. In addition to giving airlines the freedom to set fares, deregulation removed restrictions on entry and exit, allowing the carriers to expand and rationalize their route structures.[1] This flexibility led in the 1980's to a dramatic expansion of hub-and-spoke networks, where passengers change planes at a hub airport on the way to their eventual destinations. By funneling all passengers into a hub, such a system generates high traffic densities on its "spoke" routes. This allows the airline to exploit economies of scale from frequent operation of large aircraft on the spokes, yielding lower cost per passenger.[2]

Restructuring of the industry in response to deregulation has also led to renewed interest among economists in the determinants of airfares in individual city-pair markets. This new line of research contains notable contributions by Berry (1990), Borenstein (1989), Call and Keeler (1985), Graham, Kaplan, and

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[1]For discussion of the impact of the new regulatory environment on airline operations, see Bailey and Williams (1988), Bailey, Graham and Kaplan (1985), Levine (1988), Moore (1986), and Morrison and Winston (1986). A measure of the increase in "hubbing" is provided by McShan and Windle (1990), who show that the total enplanements of each carrier became increasingly concentrated at selected airports over the 1980's.

[2]For documentation of economies of scale (or, equivalently, economies of density), see Caves, Christensen, and Tretheway (1984). Using the same type of estimating equation, McShan and Windle (1990) show that airline costs fall as the extent of "hubbing" grows. Another benefit of a hub-and-spoke system from a passenger's point of view is that there is no need on a multiple-segment trip to change carriers at the intermediate airport. For an analysis of the valuation placed on this convenience, see Carlton, Landes, and Posner (1980). For a related analysis of coordination between network carriers, see Carlton and Klamer (1983).

Sibley (1983), and Morrison and Winston (1989, 1990). These studies typically explore the connection between airfares and market-specific measures of demand (city populations and incomes, tourism potential), cost (flight distance, load factors), and competition (number of competitors, market share). However, even though the airline industry has undergone a hub-and-spoke revolution, the impact of network characteristics on fares in individual markets has received little attention in this literature.[3] Given that networks play a critical role in lowering airline costs, this may be a serious omission. When a hub-and-spoke network successfully raises traffic densities, ticket prices are likely to reflect the resulting lower cost per passenger. Fare regressions that omit network variables may fail to capture such effects.

The purpose of the present paper is to fill this gap in the literature by studying the impact of network characteristics on airfares in an empirical framework that includes many of the traditional market-specific variables. Our central hypothesis is that any force that increases traffic volume on the spokes of a network will reduce fares in the markets that it serves. This effect arises because of increasing returns on the spokes. For example, since a large network (as measured by the number of city pairs that it connects) offers many potential destinations to the residents of an endpoint city, its spokes should have higher traffic densities than the spokes of a small network. With costs correspondingly lower, fares in the individual markets served should be lower in the large network, other things equal. Similarly, holding size

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[3]Borenstein (1989) and Morrison and Winston (1989, 1990) include measures of the carrier's airport dominance at the endpoints of a market. Although this variable provides some information about the network, it does not capture the type of network effects studied in this paper. Using an approach somewhat similar to ours, Berry (1990) includes the numbers of routes served out of each endpoint city as explanatory variables. These variables, however, are not grounded in an explicit model of network effects.

fixed, a network that connects large cities should have higher traffic densities on its spokes (and thus lower fares in individual markets) than one serving small cities. Our emphasis on network variables, which include measures of network size and "population potential," distinguishes the present fare study from earlier research.

Two other distinguishing features of the paper are noteworthy. First, although our main hypothesis relates to the effect of traffic densities on fares, we do not attempt to measure densities directly.[4] Instead, network characteristics are used to infer densities in an indirect manner. This approach avoids the simultaneity between traffic and fares, linking fares instead to the exogenous features of airline networks.

Second, rather than focus on all types of city-pair markets, we restrict attention to those markets where travel involves a four-segment round trip through a hub airport. Two-segment markets, where travel requires no change of plane (e.g., New York-Chicago, Los Angeles-San Francisco), are thus not considered. The reason is that since two-segment markets are likely to have large cities as endpoints, high traffic density can be achieved on the route (and economies of scale exhausted) without the help of a hub-and-spoke system. Therefore, the characteristics of the network serving many two-segment markets are probably not critical in explaining fares. Four-segment markets, on the other hand, are likely to include at least one small or medium-size endpoint city. In this case, the traffic-collection function of the network plays a critical role in reducing the costs of serving the minor endpoint. The network's characteristics should thus have an effect on fares in the market.

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[4]Graham, Kaplan, and Sibley (1983) include traffic levels on the right-hand side of their fare equation. In a similar vein, Borenstein (1989) uses the airline's load factor in the market as an explanatory variable. Both studies undertake appropriate simultaneity corrections.

Our focus on 4-segment markets is unique and also bears on the current concern regarding excessive concentration at certain hub airports. As a result of recent mergers, TWA and Northwest now dominate the hubs at St. Louis and Minneapolis-St. Paul, respectively. This domination makes higher fares likely for passengers originating or terminating at these airports, a prediction that has been partly confirmed by Borenstein (1990), U.S. General Accounting Office (1988), U.S. Deparment of Transportation (1989), and Werden, Joskow, and Johnson (1989). Although concern about the effects of concentration is certainly warranted, discussions of the issue have overlooked the fact that local traffic accounts for just part of the enplanements at the dominated hubs (37% in the case of St. Louis, according to the GAO), with connecting traffic making up the rest. Given that connecting passengers often have a choice of hubs through which to make their trip, concentration at a particular hub does not mean elimination of competition in the 4-segment markets. Moroever, the larger hub network created by a merger is likely to have lower costs per passenger than the original networks as a result of higher traffic densities. The concentrated hub may thus offer more effective "interhub" competition in the non-hub city-pair markets than did the pre-merger carriers, leading to lower fares in such markets. The magnitude of such effects, which offer a counterweight to fare increases for hub-originating or hub-terminating passengers, are computed using the fare equations estimated below.

The data for this study is drawn from Databank 1A of the Department of Transportation's <u>Origin and Destination Survey</u>, a source that has been used by many other researchers. The period of study is the 4th quarter of 1985. This data set, which comes from a 10 percent quarterly sample of all airline tickets, shows the dollar fare for each observed itinerary (i.e., carrier-route combination). The itinerary data is used to reconstruct the airline networks in 1985, and the resulting network characteristics are then merged with the fare observations to carry out the fare regressions.

The paper is organized as follows. Section 2 discusses the comparative-static properties of a simple theoretical model of a hub-and-spoke system, which are used to generate empirical hypotheses. Section 3 explains how the network characteristics are computed and shows the key features of the major networks operating in 1985. Section 4 describes the market-specific variables used in the fare regressions, and Section 5 presents the empirical results. Section 6 simulates the estimated equation to predict the effect of the TWA-Ozark and Northwest-Republic mergers, and Section 7 offers conclusions.

2. A Simple Network Model

This section sketches Brueckner and Spiller's (1989) model of a hub-and-spoke network in order to develop empirical hypotheses.[5] Suppose that a monopoly airline operates the four-city network depicted in Figure 1, where city H is the hub. Residents of each city have a demand for air travel to every other city of the network, including the hub. Demand is symmetric across city-pairs, with $D(Q)$ giving the inverse demand function for round-trip travel in each market. Q is total traffic in both directions in the market, so that Q_{AB}, for example, equals the number of passengers making round trips from A to B and back plus passengers making round trips from B to A and back. Letting $R(Q) = QD(Q)$ be the revenue function, total revenue from the network is then

$$R(Q_{AB}) + R(Q_{AC}) + R(Q_{BC}) + R(Q_{AH}) + R(Q_{BH}) + R(Q_{CH}) \qquad (1)$$

(the last three terms are revenues in city-pair markets that include the hub).

[5]For another network model, see Spiller (1989).

Costs are represented by the function $c(Q)$, which gives the total cost of carrying a round-trip traffic volume of Q on a particular spoke of the network. With increasing returns to scale (or, following Caves, et al. (1984), increasing returns to density), c satisfies $c' > 0$ and $c'' < 0$. As noted above, the reason for increasing returns is that higher traffic on a spoke allows the airline to operate larger, more efficient aircraft and to use its fixed ground facilities and personnel more intensively. Given that each spoke of the network carries traffic in three city-pair markets, total network cost is equal to

$$c(Q_{AB}+Q_{AC}+Q_{AH}) + c(Q_{AB}+Q_{BC}+Q_{BH}) + c(Q_{AC}+Q_{BC}+Q_{CH}). \qquad (2)$$

To maximize profit [(1) minus (2)], the monopolist sets marginal revenue in each city-pair market equal to the marginal cost of a passenger in the market. In a hub-inclusive city-pair market such as AH, marginal cost is simply c' for the AH spoke, so that the first-order condition is

$$R'(Q_{AH}) = c'(Q_{AB}+Q_{AC}+Q_{AH}). \qquad (3)$$

In a non-hub market such as AB, marginal cost is the sum of the c' expressions for the two spokes connecting the cities, so that the first-order condition is

$$R'(Q_{AB}) = c'(Q_{AB}+Q_{AC}+Q_{AH}) + c'(Q_{AB}+Q_{BC}+Q_{BH}). \qquad (4)$$

Since the solution to the monopolist's problem is symmetric across markets, the model is easily extended to a network containing n non-hub cities plus the hub. Let Q_{NH} be traffic in each non-hub market and Q_H be traffic in each hub-inclusive market. Profit from the network is then

$$(n(n-1)/2)R(Q_{NH}) + nR(Q_H) - nc(Q_H+(n-1)Q_{NH}) \qquad (5)$$

(note that there are $n(n-1)/2$ non-hub markets, n hub-inclusive markets, and n spokes). The monopolist's first-order conditions have the same form as (3) and (4).

When specific functional forms are imposed, this model can be used to analyse the effects of various changes in the monopolist's environment. If marginal revenue and cost are both linear, with $R'(Q) = t - Q$ and $c'(Q) = 1 - zQ$, where $t, z > 0$, then the following results can be established. First, an increase in n, the number of cities served by the network, raises traffic and lowers fares in all markets. As explained in the introduction, the reason is that the resulting higher traffic densities allow more effective exploitation of increasing returns. Second, higher demand (a larger t) raises traffic in all markets while changing fares in a direction that depends on the degree of increasing returns. Fares in the non-hub markets fall when increasing returns are strong (when z is large) and rise otherwise, an outcome familiar from standard monopoly models.[6] This result shows that the high demand associated with large city populations, for example, will lead to lower fares as long as increasing returns are strong.

Brueckner and Spiller (1989) provide a detailed analysis of the effects of competition in the four-city model. They discuss the effect of "interhub" competition in market AB (where another airline serves the market through a symmetric hub system), "direct" competition in AB (where a competitor provides non-stop service in the market), and "leg" competition in market AH (where an isolated competitor serves this hub-inclusive market). Although the effects of competition vary somewhat across cases, the typical outcome is that competition leads to lower fares in the market where it occurs while <u>raising fares in all other markets in the network</u>. The intuitive explanation of this result is

[6]Fares in the hub-inclusive markets fall as t rises.

straightforward. Introduction of competition in a market (AB, for example) lowers traffic on the network spokes (AH and BH) that serve the market. With increasing returns, this traffic leakage raises the marginal cost of a passenger on each spoke. While competitive pressure in AB counteracts the higher marginal costs, reducing fares in the market, other markets that use the affected spokes (markets AC, BC, AH, and BH) lack competition. As a result, fares in these markets rise and traffic levels fall.[7] This outcome is a consequence of increasing returns together with the cost complementarities inherent to a hub-and-spoke network. In such a setting, competition generates negative externalities outside the market where it occurs.

The above results, along with those dealing with demand and network size, are not realistic because the benchmark case is a monopoly hub-and-spoke system, none of which exist. However, the conclusions are suggestive and can be used to motivate an empirical study. The results lead to the following empirical hypotheses: (i) a market served by a large hub-and-spoke network should have lower fares than a market served by a small network; (ii) when increasing returns are strong, a market with high demand should have lower fares than a market with low demand; (iii) a market where competition occurs should have lower fares than a market without competition; (iv) a market served by a network facing widespread competition (and thus a large traffic leakage) should have higher fares than a market served by a network facing little competition. In the next section of the paper, we discuss some of the network variables used to test these hypotheses.

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[7]The reduction in traffic in the AC and BC markets in turn raises marginal cost on the CH spoke, which leads to a higher fare and lower traffic in the CH market.

3. Network Characteristics

The data for the study are drawn from Databank 1A (DB1A) of the DOT's Origin and Destination Survey for the fourth quarter of 1985. This databank is generated quarterly from a 10 percent sample of all airline tickets written in the U.S. Each record contains an airline itinerary (a route flown on a given carrier), a dollar fare, and the number of passengers observed on the itinerary at the given fare during the quarter. The distance of the trip and the fare class are also shown.

To construct network characteristics, we restrict attention to DB1A records with itineraries of the following type: 2-segment same-carrier round trips and 4-segment same-carrier round trips where the intermediate (hub) airport is the same in both directions.[8] After imposing several other restrictions[9] and dropping repeated itineraries (which arise because of multiple fares), we are left with 23,428 unique 4-segment itineraries and 6319 unique 2-segment itineraries.[10] This data set, which records traffic patterns

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[8]The routing for a 2-segment round trip lists three aiports (i.e., LAX-SFO-LAX), while a 4-segment routing lists five airports (i.e., LAX-DFW-JFK-DFW-LAX). Along with 1-segment trips, which typically represent shuttle flights, these 2- and 4-segment records cover the vast majority of airline travel in the U.S. Moreover, 4-segment travel is quantitatively significant. Of the 1,356,000 passengers observed making 2- or 4-segment trips (restricted as described above), somewhat less than one-third (405,000) made 4-segment trips (recall that these numbers represent a 10% sample).

[9]Records whose itineraries contain travel outside the continental U.S. are excluded, as are records with a fare of less than $10 (the latter criterion, which is meant to eliminate frequent-flier tickets, follows Borenstein (1989)). Also, we restrict attention to records showing 2 or more passengers (this corresponds to total quarterly traffic on the route of at least 20 passengers).

[10]Since different itineraries can be used within one market, the above figures overstate the number of city-pair markets observed in the data. The total number of 4-segment markets is in fact 8179, and the number of 2-segment markets is 2170. Traffic is not always observed in both directions in a market (this is often true in thin markets).

among a chosen set of 267 cities,[11] is used to construct the network characteristics. It is important to note that, as in previous research, each airport is treated as a different endpoint.[12] Therefore, multiple-airport cities such as New York and Los Angeles contain several distinct destinations.[13]

From the discussion in Section 2, we expect the fare in an individual market to be a decreasing function of network size. Although size was represented by n (the number of cities served) in the simple model of the last section, that model was based on the assumption that travel occurred in each possible city-pair market. Since this will not be true in real networks, n is not necessarily a good predictor of traffic flows on the network spokes (and thus of cost per passenger). A better measure of these flows is total 4-segment city-pairs connected by the network, denoted NTWCITP4. When the spokes

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[11] Construction of this list is explained below when the regression data set is discussed.

[12] See, for example, Borenstein (1989). Merging the different airports requires arbitrary decisions and, in our case, leads to computational difficulties.

[13] A problem with the data is that some carriers indicate a destination or origin in the New York and Washington, D.C., areas by the overall city codes NYC and WAS without listing the specific airport used. While Borenstein (1989) deletes such records, this solution is inadvisable in our case because it discards information critical to the construction of the networks. Our solution is as follows. For each record including a NYC or WAS code, we consulted the Official Airline Guide to find the actual airport or airports used by the carrier on the route. If a single airport appeared, its name replaced the NYC or WAS designation. When a carrier was listed as flying to several airports, we randomly replaced the NYC or WAS designation with the code of one of the airports used. For example, if the OAG showed that a carrier using an NYC code flew to La Guardia (LGA) and Newark (EWR), the NYC designation was replaced with LGA with probability 1/2 and by EWR with probability 1/2. This solution is imperfect, but it preserves valuable information.

of the network are symmetric, the 4-segment portion of total traffic on each spoke will be proportional to NTWCITP4.[14]

Based on the earlier analyis, we also expect fares in the market to depend on the populations of cities served by the network, with larger cities leading to lower fares when increasing returns are sufficiently strong. To capture this effect, we compute the variable NTWAVGPP, which equals the average "population potential" of 4-segment markets in the network. A market's population potential equals the square root of the product of the city populations (population is measured in 10,000's).[15] This quantity is summed across 4-segment city pairs and divided by NTWCITP4 to arrive at NTWAVGPP. We expect fares to be inversely related to NTWAVGPP under strong increasing returns.

The previous analysis also showed that competition in both 4-segment markets (e.g., AB) and 2-segment markets (e.g., AH) raised fares elsewhere in the network. The first effect is captured by the variable NTWCOM4, which equals the fraction of the network's 4-segment markets where at least one competing carrier is present. Competing carriers could provide service through the same hub, a different hub, or could provide direct (nonstop) service.[16]

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[14]Referring to (5), total non-hub market traffic along each spoke will be proportional to NTWCITP4 divided by n. In the more realistic case where the network spokes are asymmetric, this divisor will differ from n, being larger (smaller) when the spoke is heavily (lightly) travelled. Such asymmetry is taken into account below by the introduction of two additional variables indicating the fraction of network city pairs that include the market's origin city and the fraction that include the destination. These variables are discussed below in the section dealing with market-specific variables.

[15]In the case of big cities, the population of the entire metropolitan area containing the airport is used (the actual city population is used for small urban areas). Details are available on request.

[16]One feature of the DB1A data is that nonstop service in a market is indistinguishable from same-plane one-stop service (both yield two ticket

The second effect is captured by NTWCOM2, which equals the fraction of the network's 2-segment markets experiencing competition (two segment markets are those where one endpoint is the hub). Competitors could offer either 2- or 4-segment service. We expect fares in a given market to be increasing in both NTWCOM4 and NTWCOM2.

Table 1 shows the values of the above variables for the major networks along with some other variables of interest (networks with NTWCITP4 values below 60 are not shown). POINTS equals the number of cities connected to the hub. Since POINTS is computed as the number of cities from among our 267 that appear in 2- or 4-segment itineraries, it may understate the number of points actually served by the carrier (our list may exclude actual endpoints, or traffic may not be observed to some cities on our list that are in fact served). U4 is the network's 4-segment "utilization rate," which equals NTWCITP4 divided by the number of possible 4-segment markets, POINTS*(POINTS-1)/2. U2 is the network's 2-segment utilization rate, equal to the number of 2-segment markets (not shown) divided by POINTS. Finally, NTWCOM4S equals the fraction of the network's 4-segment markets experiencing "same-hub" competition (where the competitor uses the same hub).

Table 1 shows a large range of network sizes in 1985. The largest system in terms of city pairs connected is American's Dallas-Ft. Worth network, which serves 1564 city pairs. The Atlanta networks of Delta and Eastern are close behind in size, followed by the networks of US Air at Pittsburgh and United at Chicago-O'Hare. The population potential of networks also varies considerably. The Denver/Frontier, Minneapolis/Republic, and Phoenix/America West networks show low values of NTWAVGPP, indicating service to small cities, while the high NTWAVGPP values for the Denver/Continental, Kansas City/Eastern,

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coupons for a round trip, and thus show up as 2-segment trips). As measured, direct (2-segment) service may thus involve a stop.

Chicago/Midway, and St. Louis/TWA networks indicate that these systems tend to connect large cities.

The U2 and U4 variables indicate how successful a network is in generating traffic among the cities that it serves. A relatively low value of U4, for example, indicates that service is observed in a small fraction of the 4-segment markets in which connections are feasible. On this criterion, relatively unsuccessful networks include Baltimore-Washington/Piedmont, Denver/United, Kansas City/Eastern, Chicago-O'Hare/United, and Philadelphia/US Air, all of which have U4 values below .200. Successful networks, on the other hand, include Atlanta/Delta, Charlotte/Piedmont, Denver/Frontier, Chicago/Midway, Memphis/Republic, Phoenix/America West, Pittsburgh/US Air, Salt Lake City/Western, and St. Louis/TWA, all of which have U4 values above .350. The underlying reasons for variation in U4 are not immediately apparent. A low value of NTWAVGPP might be expected to lead to a low U4, but Table 1 shows numerous counterexamples. Similarly, network size is not a good predictor of U4, as inspection of the table shows.[17]

The variable U2, which naturally takes higher values than U4, also shows some variation across networks. A U2 value below one indicates that some cities that are endpoints of 4-segment trips are <u>not</u> observed as endpoints for 2-segment trips. Apparently, this outcome can occur when the hub itself is not an attractive destination for residents of the non-hub cities of the network,[18] or when some of these cities are so small that they generate too little traffic

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[17]Like all of the network calculations in this paper, the utilization rates do not capture flight frequency, which ideally would be taken into account in appraising the "success" of a network.

[18]Also, the distance to the hub from some of the network cities could be so short that air travel is uneconomical.

in the hub-inclusive market to be observed.[19] A combination of these factors may explain the low U2 values for the Baltimore-Washington/Piedmont, Dayton/Piedmont, and Philadelphia/US Air networks.

The NTWCOM4 numbers show that networks experience varying degrees of competition in their 4-segment markets. At one extreme, competition is present in all of the 4-segment markets served by the Kansas-City/Eastern network. At the other extreme, United faced at least one competitor in just 40% of the 4-segment markets served out of its San Francisco hub. Other networks facing relatively low levels of 4-segment competition are Charlotte/Piedmont, Dayton/Piedmont, Denver/Frontier, Dallas-Ft.Worth/American, Detroit/Republic, Minneapolis/Republic, Philadelphia/US Air, Pittsburgh/US Air, and St. Louis/Ozark. Interestingly, three of the carriers in this list (Frontier, Republic, and Ozark) were acquired in mergers shortly after 1985. Values of NTWCOM2 show similar variation, with the Chicago-Midway/Midway and Dayton/Piedmont networks noteworthy for the small amount of competition in their 2-segment markets.[20]

Low values of NTWCOM4S indicate that few of the network's 4-segment markets experience same-hub competition, implying that the hub airport does not support another carrier's hub-and-spoke network. This, of course, does not preclude competition in the 4-segment markets, which occurs through other hubs or in direct service. Table 1 shows that low (or zero) values of NTWCOM4S are often accompanied by high values of NTWCOM4, as in the case of Philadelphia/US Air.

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[19] When traffic is low, the city has a better chance of showing up in one of many non-hub markets than in the single hub-inclusive market.

[20] The Midway figure highlights the fact the Midway is treated as a different destination than Chicago-O'Hare.

4. The Regression Data Set

To generate the regression data, we return to the initial set of 4-segment records, including those with repeated itineraries due to multiple fares. Since we wish to avoid records that represent very thin markets or unusual fares, records with fewer than four passengers are excluded.[21] We also exclude records where the fare class was not YD (coach discount) for all segments of the trip (this eliminates about one-third of the data). The reason for this exclusion is to focus on the airline's most competitive fares. YD fares should be most closely linked to costs, and they also should be least contaminated by the effects of frequent-flier programs, which have been discussed at length in the literature (see especially Borenstein (1988, 1989)). Next, the fare data is merged with the network information calculated above, and records showing travel within a small network (where NTWCITP4 is less than 10) are excluded. This leaves 10,523 records. The last step is to exclude records where the origin or destination is a hub for the carrier. Since such a trip involves travel between two of the carrier's hubs, it in effect occurs within two networks. This last exclusion leaves 9964 records.[22]

As a result of multiple fares, there are 6054 distinct itineraries among these 9964 observations. 3888 of these itineraries have a single fare, 1236 have two observed fares, 505 have three, and the balance (7%) have four or more observed fares. In performing the regressions, we take two alternative

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[21]These 4-passenger records reflect the results of the randomization described in footnote 13.

[22]Our list of 267 cities was generated by taking all cities observed in the 4-segment data and excluding a sufficient number to satisfy memory limits in the Fortran program that calculated the network characteristics. The 40 cities excluded were the 40 with the smallest populations among those showing zero passenger enplanements in the FAA data (zero-enplanement cities in the FAA data are served by commuter carriers). The regression data, of course, excludes records with cities not on the list.

approaches. One uses all the data, treating each fare observation as distinct.[23] The other approach treats each itinerary as a single observation, setting the fare value for those itineraries that are repeated equal to the passenger-weighted mean of the multiple fares. While the latter approach throws away information and may also create serious aggregation bias (see Elrod (1983)), it is presented for purposes of comparison. Finally, it should be noted that since our specification allows fares in a market to vary directionally, itineraries in opposite directions within one market are not viewed as the same.[24]

Each observation contains values for the network-specific variables NTWCITP4, NTWAVGPP, NTWCOM4, and NTWCOM2.[25] Two additional variables that are jointly market- and network-specific are also computed. The first variable, denoted ORIGSHR, is equal to the share (fraction) of the network's 4-segment city-pair markets that include the observation's origin city. Analogously, DESTSHR equals the share of the network's 4-segment markets that include the destination city. ORIGSHR and DESTSHR are used to account for the fact (noted above) that the origin and destination cities may not be equally connected to the network, making NTWCITP4 an imperfect representative of traffic flows on

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[23]In this respect, our data set differs from that of Borenstein (1989). By focusing on thick markets, Borenstein had enough fare variation in each market to estimate separate equations for various fare quantiles (20%, median, etc.).

[24]Calculation of the network variables described above does not, of course, depend on the direction of travel in a market.

[25]In addition to those shown in Table 1, a number of small networks (with NTWCITP4 values between 10 and 60) appear in the regression data set. These are Indianapolis/US Air, Denver/Aspen, Memphis/Delta, Charlotte/Eastern, Houston/Eastern, Tampa/Northwest, Washington-Dulles/New York Air, San Francisco/Air Cal, John F. Kennedy/TWA, Syracuse/Empire, Los Angeles/Western, Orlando/Florida Express, and Chicago-O'Hare/Air Wisconsin.

the spokes. To see this, note that a large value of ORIGSHR means that traffic is observed between the origin and many other points in the network. This means that traffic density should be high on the spoke between the origin city and the hub, leading to low cost per passenger over a portion of the route and thus to low fares in the market. For the same reason, a high value of DESTSHR should lower costs on the spoke connecting the destination to the hub, again leading to low fares in the market. Note that, holding ORIGSHR and DESTSHR constant, an increase in NTWCITP4 simultaneously increases the number of cities connected to origin and destination, lowering costs on both spokes simultaneously and thus reducing fares in the market.[26]

The set of purely market-specific variables is as follows. MKTPP is the population potential in the market, equal to the square root of the product of the city populations. This is a demand variable, and its effect on fares should be negative when increasing returns are strong. Another demand variable is INCORIG, which equals per capita income for the origin city.[27] Its effect on fares could be in the same direction as that of MKTPP (negative), but price discrimination on the basis of city income could lead to a different result.[28]

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[26]An alternative approach is to use the numbers of city pairs that include the origin and destination as explanatory variables, dropping NTWCITP4 (these variables are the product of ORIGSHR (DESTSHR) and NTWCITP4). Our approach, however, is superior on theoretical grounds since it recognizes that the aircraft sizes in an airline's fleet (and thus cost per passenger) are chosen partly on the basis of average traffic density on the spokes of its network, which is in turn related to NTWCITP4. In effect, the specification without NTWCITP4 implicitly assumes that aircraft types can be tailored to exactly suit densities on individual spokes, which may be unrealistic.

[27]The per capita income figure for the proper geographic unit (metropolitan area vs. city; see footnote 15) is used.

[28]Another possibility is that the demand for service "quality" rises with income, and that fares rise to reflect the resulting higher cost. The quality dimension could include load factor (with high-income consumers willing to pay for less-crowded aircraft) as well as flight frequency.

We do not use destination income as an explanatory variable on the belief that carriers' pricing policies are directionally sensitive and that this variable would have little or no effect on the demand for trips out of the origin. The final demand variable is TEMPDIF, which equals the mean January temperature at the destination minus the mean temperature at the origin. A large value of TEMPDIF, which indicates a market with high tourism potential, should reduce fares as carriers respond to the elastic travel demands of vacationers.[29]

DIST equals the one-way distance of the trip, and is expected to have a positive impact on fares. Following earlier research, we also include dummy variables to represent the four slot-controlled airports: Chicago-O'Hare (ORD), Washington-National (DCA), La Guardia (LGA), and John F. Kennedy (JFK). A given variable assumes the value one if either the origin or destination for the market is the airport in question.[30] Since slot control restricts the supply of airline service, the dummy coefficients are expected to be positive.

To measure the effects of competition, we compute the total number of carriers competing with the observed carrier in the market, denoted MKTCOM. There are three possible types of competition (4-segment same-hub, 4-segment interhub, or direct), but distinguishing between them added little to the results.[31] While it is possible to use the MKTCOM variable directly in the

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[29]We also experimented with Borenstein's (1989) tourism variable, city hotel receipts as a fraction of personal income, but it performed poorly.

[30]We tried Borenstein's (1989) approach of including dummies for a large number of congested airports. The results were largely unaffected by this alteration, and moreover, many airport variables had insignificant or significantly negative coefficients, contrary to the rationale for their use.

[31]The same carrier is counted as a competitor more than once if it offers several routings in the market. For example, if a carrier offers both interhub and direct service, it is counted as two competitors. Since the availability of several routings yields greater scheduling convenience, a

regressions,[32] more insight is gained by following Morrison and Winston (1989) and constructing a set of variables that allows the effect of extra competition to depend on the initial number of competitors. Accordingly, we created the variables MKTCOM1, MKTCOM23, and MKTCOM4+, defined as follows:

$$\text{MKTCOM1} = \begin{cases} \text{MKTCOM if MKTCOM} = 0,1 \\ 1 \text{ otherwise} \end{cases}$$

$$\text{MKTCOM23} = \begin{cases} 0 \text{ if MKTCOM} = 0,1 \\ \text{MKTCOM-1 if MKTCOM} = 2,3 \\ 2 \text{ otherwise} \end{cases}$$

$$\text{MKTCOM4+} = \begin{cases} 0 \text{ if MKTCOM} = 0,1,2,3 \\ \text{MKTCOM-3 otherwise} \end{cases}$$

MKTCOM1's coefficient gives the effect on fares of increasing MKTCOM from 0 to 1; MKTCOM23's coefficient gives the effect of increasing MKTCOM from 1 to 2 or from 2 to 3; MKTCOM4+'s coefficient gives the effect of increasing MKTCOM from 3 to 4 and beyond. We expect the coefficients of these successive variables to be negative and declining in absolute value, indicating diminishing returns to competition.

We again follow Morrison and Winston (1989) by including a variable to measure potential competition in the market.[33] This variable, denoted MKTPCOM, is equal to the number of carriers that serve both endpoints of the market but

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carrier offering such flexibility provides more effective competition in the market than a carrier that offers a single routing.

[32]Results from this specification are shown in the appendix as part of the discussion of two-stage least squares estimates.

[33]For other discussions of potential competition, see Morrison and Winston (1987) and Peteraf (1986).

do not provide service in the market itself. Finally, in order to capture carrier fixed effects, a set of carrier dummy variables is included in the estimating equation (American is the default carrier). In addition to controlling for differences in the airlines' cost structures, these variables should net out the effect of frequent-flier programs (carriers with attractive programs can charge higher fares). It should be noted that failure to include the airline dummies could lead to biased coefficients of the network variables, which could then be contaminated by carrier fixed effects.

It is important to realize that the issue of airport dominance, which figures prominently in the papers of Borenstein (1988, 1989) and Morrison and Winston (1989, 1990), does not arise in the present setting. The reason is that our focus on 4-segment trips (and our subsequent elimination of itineraries where the origin or destination is a hub for the carrier) means that no carrier exercises airport dominance at the endpoints of a market where it is observed.[34] It is interesting, however, to consider what happens to a carrier's fares when a market endpoint is dominated by another carrier (such markets are in fact present in the data). To address this issue, we construct dummy variables ORIGCONC and DESTCONC, which take the value one when the origin or destination airport is a concentrated hub (with a single carrier accounting for more than 60% of total enplanements). These airports are Charlotte, Dayton, Dallas-Ft. Worth, Chicago-Midway, Memphis, Salt Lake City, and Pittsburgh. On the one hand, the high fares charged by the airport's dominant carrier should allow fringe competitors to charge similarly high fares,

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[34] A single carrier may provide the only service at some small airports, but the absence of entry barriers at such endpoints means the airports are not dominated. In light of this observation, the interpretation of Borenstein's airport-enplanement-share dominance variable is not clear. The high value of this variable at a small, single-carrier airport does not imply domination of the airport by that carrier.

implying positive coefficients for the concentration dummies. On the other hand, fringe competitors attempting to gain a foothold at the airport may be forced to charge lower fares than the dominant carrier in order to attract passengers.[35] With the dominant carrier's fares already high, the result may be an average fare level for the competitor, implying insignificant dummy coefficients.

Table 3 shows the variable means as well as minimum and maximum values for the non-dummy variables. With the exception of FARE, these values are computed on the "mean-fare" data set, where repeated itineraries are eliminated (the mean FARE is computed using all 9964 observations). Note that the means of the carrier dummies give the frequency with which the carriers appear in the mean-fare data set.[36] Note also that the variable NPASS, which gives total passengers per itinerary, is shown (this variable is not used in the regressions). The variables MKTCOM and MKTPCOM, which have large ranges, are distributed as follows: MKTCOM equals zero for 21% of the observations (indicating no competition in the market). It equals 1 for 16%, 2 for 15%, 3 for 11%, 4 for 9%, 5 for 7%, and 6 or more for the remaining 21% of the observations (the median value is 2). MKTPCOM equals zero for 14% of the observations (indicating no potential competition). It equals 1 for 22%, 2 for

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[35]Beyond the effect of entry barriers, the dominant carrier is presumed to exercise market power because airport dominance enhances the attractiveness of its frequent-flier program and also leads local travel agents to favor its computer reservation system over those of competitors (see Borenstein (1989)).

[36]American accounts for 19% of the itineraries. An anomaly is the low frequency of Delta observations. The reason for this is that the data shows Delta as writing very few coach discount (YD) tickets, which are those represented by the data. This pattern also appears in the DB1A data for other years.

22%, 3 for 19%, and 4 or more for the remaining 23% of the observations (the median value is again 2).

5. Empirical Results

The dependent variable for the regressions is the natural logarithm of FARE.[37] With the exception of distance, which appears in log form as LDIST, all the explanatory variables are untransformed. The main regression results are presented in Table 4. The first column of the table shows the coefficients for an equation estimated on the entire data set (described as ALL). The dummy coefficients for this equation are presented in Table 5 (the equation does not include the variables ORIGCONC and DESTCONC, which are added later).

The results in the first column provide strong support for the analytical framework developed in this paper. The coefficient of NTWCITP4 is negative and significant, indicating that fares are low, as predicted, when the market is served by a large network. The strength of this effect is indicated in Table 6, which shows that fares in a market fall by half a percent when the network grows in size by 100 city pairs.[38] The coefficients of ORIGSHR and DESTSHR are also negative and significant, indicating that, holding NTWCITP4 fixed, fares are low when the origin and destination are well-connected to the rest of the network (recall that spoke traffic will be high and cost per passenger low in this case). Table 6 shows that when ORIGSHR (DESTSHR) increases by one standard deviation (.04 for both), fares fall by 3.4% (3.7%). Since the coefficients of these variables are not significantly different from one another, these effects are in fact indistinguishable.

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[37]FARE gives the round-trip ticket price.

[38]Since the dependent variable is in log form, this number comes from multiplying NTWCITP4's coefficient by 100. The same principle applies to other calculations in Table 6.

The coefficient of NTWAVGPP is also negative and significant, indicating that when the network serves large cities, fares in any given market are low. This result suggests that the cost savings from high traffic densities in a network serving large markets are passed on to consumers. While this outcome requires strong increasing returns in the monopoly model discussed above, its emergence here might be the result of competitive pressures combined with moderate or weak increasing returns. Table 6 shows that increasing NTWAVGPP by 41 (one standard deviation) lowers fares in a given market by 1.9%.

The network competition variables NTWCOM4 and NTWCOM2 both have positive coefficients, although only NTWCOM4's is significant. Thus, as predicted, a network with pervasive competition in its 4-segment markets has high fares as a result of the cost-increasing leakage of traffic to competitors. A one-standard-deviation increase in NTWCOM4 (an increase of .15) raises fares by 2.9%. Although 2-segment competition was also expected to raise fares, the insignificant effect of NTWCOM2 could be due to the relatively small variation in this variable across networks.

Taken as a group, the above network variables are strongly significant, with the F statistic for the joint test of zero coefficients significant at the .0001 level. One implication of this finding is that fare equations that omit network variables are misspecified.[39] More generally, our results provide the first concrete evidence linking a detailed set of network charateristics to airfares. This evidence indirectly confirms the importance of networks in lowering airline costs.

Turning to the market-specific variables, distance has the expected positive effect on fares, with LDIST's highly-significant coefficient

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[39] If the estimated fare equation controls for traffic densities on the spokes (properly treating them as endogenous), then network variables could be omitted.

indicating an elasticity of 0.4. MKTPP's significantly negative coefficient shows that fares are low when the market contains large cities, with a one-standard-deviation increase in this variable (equal to 143) lowering fares by 0.9%. While this effect follows that of NTWAVGPP, it is interesting to note that the network variable's coefficient is seven times as large in absolute value as MKTPP's. This suggests that network population potential is more important in reducing fares than market potential, a finding that makes sense given that the network spokes connecting the cities in a particular market carry traffic bound for many other destinations.

The significantly positive coefficient of INCORIG shows that residents of high-income cities pay high fares. Price discrimination would explain this outcome if consumer demand for air travel were to become less elastic as income grows. Whatever the explanation, Table 6 shows that a $1210 increase (one standard deviation) in per capita income raises fares by 1.2%. TEMPDIF's coefficient is negative and significant, indicating that markets where the destination's January temperature is high relative to the origin's have low fares. The magnitude of this tourism effect is indicated in Table 6, which shows that a 22 degree increase in TEMPDIF lowers fares by 1.8%.

The MKTCOM coefficients, all of which are negative and significant, show diminishing returns to market competition, as expected. The magnitude of MKTCOM1's coefficient shows that addition of the first competitor to a monopoly market lowers fares by 7.7%. Addition of a second or third competitor reduces fares by a further 3.4%, while the addition of an extra competitor beyond three lowers fares by a further 0.6%.[40] Also, the addition of a potential competitor to the market (a unit increase in MKTPCOM) lowers fares by 1.6%. It is

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[40]The MKTCOM coefficients are significantly different from one another in pairwise tests.

interesting to note that the percentage impact on fares of adding the first competitor to a monopoly market is larger than any other effect listed in Table 6.

Turning to the dummy coefficients shown in Table 5, we see that slot control leads to higher fares at only two of the four controlled airports (the coefficients of LGA and JFK are insignificant). Fares are higher by 4.7% when the origin or destination is Chicago-O'Hare, while a Washington-National origin or destination raises fares by 9.8%. The airline dummies also show many significant carrier effects. Among the major carriers, those charging fares significantly higher than American's for a given trip are Delta (+14.6%), Eastern (+5.3%), and United (+8.0%). Those charging lower fares are Continental (-9.9%), Frontier (-9.2%), America West (-10.6%), and Piedmont (-6.6%).

The next step is to explore whether the empirical results are robust with respect to the type of sample data used. In particular, we reestimate the equation on the mean-fare sample, where repeated itineraries are collapsed into a single observation (the fare value is set equal to the passenger weighted mean of the multiple fares). While there is no good reason to prefer this approach to use of the entire sample (fare information is thrown away and aggregation bias may arise), the results are presented for comparison. The results, shown in the third column of Table 4, are somewhat different from those in the first column. In particular, the coefficients of NTWCITP4, NTWAVGPP, and MKTPP coefficients are insignificant. However, as seen in the fourth column of the table, deletion of MKTPCOM (the potential competition variable) improves the performance of the equation. With MKTPCOM deleted, the NTWCITP4 and MKTPP coefficients regain signficance, although the NTWAVGPP coefficient is still insignificant (for comparison, the second column shows results of running the same regression on the entire sample).[41] The results in column four thus lend further support to our basic hypotheses. However, lack of a good justification for the mean-fare approach makes the results based on the complete sample more credible.

The fifth column of Table 4 shows the effect of adding the airport-concentration dummies ORIGCONC and DESTCONC to the equation of column one. This change has little effect on the other coefficients. The dummy coefficients show that a concentrated origin has no significant effect on fares while a concentrated destination raises fares by 3.7%. Evidently, in competing for passengers at a concentrated origin, fringe firms keep their fares below those of the dominant carrier (leaving fares at an average level, as explained above). Since this competitive motive is absent when the destination is the concentrated endpoint (passengers are then collected at an unconcentrated origin), carriers are free to exploit the "umbrella" effect generated by the dominant carrier, which leads to high fares. These results provide an interesting extension to previous findings on airport dominance (see Borenstein (1989)).

The preceding discussion has ignored the possibility that the number of carriers competing in the market is an endogenous variable. Morrison and Winston (1989), who use similar competition variables, recognize this drawback but argue that a proper correction for endogeneity would require a complete structural model of the airline's fleet allocation process within its network.[42] While we are aware that proper handling of endogeneity would be very difficult, we experimented with a crude simultaneity correction to see how

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[41]Also, the NTWCOM4 coefficient becomes marginally significant.

[42]For analyses of entry in airline markets, see Berry (1989), Reiss and Spiller (1989), and Morrison and Winston (1990).

it affected the results. The first step was to abandon the three market-competition variables, and replace them with the single (endogenous) variable MKTCOM, equal to the number of carriers competing with the observed carrier in the market (endogeneity corrections using the three separate competition measures would have been impractical). After adding a number of instruments, the fare equation was estimated using two-stage least squares. The results, which are presented in the appendix, show that our main findings are reasonably robust to a simultaneity correction.

6. Merger Simulations

By 1987, the acquisitions of Ozark by TWA and of Republic by Northwest were complete, leading to larger consolidated hub-and-spoke networks at St. Louis and Minneapolis. These mergers created monopolies on many 2-segment routes out of St. Louis and Minneapolis, leading to concern about higher fares. Borenstein (1990), U.S. General Accounting Office (1988), Department of Transportation (1989), and Werden, Joskow, and Johnson (1989) investigated actual fare changes in the 2-segment markets, with mixed results. Fare increases did occur, but some markets experienced little fare change or saw decreases.

There has been no study of fare changes in the 4-segment markets served by the St. Louis and Minneapolis hubs. As explained above, mergers are less likely to create a monopoly in such markets because competition can continue through other hubs. For this reason, efficiency gains from the merger are less likely to be offset by anticompetitive effects, making it more likely that the 4-segment markets enjoy welfare gains.

The impact of the mergers on 4-segment fares can be studied using the equation estimated above. There are four sources of fare change in a given market when networks are blended as a result of a merger: competition in the market may be reduced, the new network is larger than either of the previous networks (NTWCITP4 rises), the network has different average population potential (NTWAVGPP changes), and it has a different level of 4-segment competition (NTWCOM4 changes). The first part of Table 7 shows how the post-merger networks differ from the original networks of the 4 merger partners. NTWCITP4 rises in each case, but population potential and competition fall for the large (acquiring) carriers while rising for the small carriers. The latter changes push fares in opposite directions (higher population potential lowers fares, while higher competition raises them); a larger network reduces fares.[43]

The fare impacts of the mergers are computed taking account of these sources of change.[44] Computations are done separately for each of the four carriers under different assumptions about initial competition in the market. Referring to Table 7, we see that on an original TWA route where Ozark was not present, the merger reduces fares by a statistically-significant 3.7%. Since there is no loss of competition on such a route, the merger's impact is found by aggregating the effects on fares of a larger network (-2.6%), lower 4-segment competition (-2.7%), and lower population potential (+1.6%), which lead to the net change of -3.7%. The same combination of forces yields a 3.6% reduction in fares on original Northwest routes where Republic was not present

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[43]These calculations are based on network characteristics computed for the 4th quarter of 1988. The NTWAVGPP and NTWCOM4 values for the merged networks were set equal to the 1988 St. Louis/TWA and Minneapolis/Northwest values. However, instead of setting NTWCITP4 equal to the 1988 numbers, the fact that all networks grew in size between 1985 and 1988 was taken into account (this growth presumably reflects the general increase in traffic). The 1988 TWA and Northwest NTWCITP4 values were deflated by average growth of all networks over 1985-1988 to arrive at estimates of the size of the TWA and Northwest networks immediately after the merger. The weights in the weighted average calculation were derived from relative shares of total enplanements at the hub airports.

[44]The calculations are based on the coefficients in the first column of Table 4.

(see the second half of Table 7). For the smaller carriers, the merger has the reverse effects on NTWAVGPP and NTWCOM4 (see the top of Table 7), and fare reductions are smaller. Fares on original Ozark routes without TWA fall by 1.3% (a value not significantly different from zero), while fares on original Republic routes without Northwest fall by 1.1% (significant only at the 10% level).[45]

While both mergers thus put downward pressure on fares in markets where there was no reduction in competition, a different picture emerges in markets where the merging carriers competed. In such cases, the network effects are countered by the effect of reduced competition, which in turn depends on the the number of competitors initially present. Table 7 shows that fares rise significantly in markets served only by the merging carriers. For example, fares on original TWA routes where Ozark was the only competitor rise by 3.9%, while fares on original Ozark routes where TWA was the only competitor rise by 6.3%. A weighted average of these fare changes (indicating average change in the market) is 4.7%. These numbers, along with the analogous Northwest-Republic figures, show that complete elimination of competition swamps the network effects of the merger, leading to higher fares.

The outcome is different when the merger does not create a market monopoly. When 1 or 2 other competitors are present in a market served by the merging carriers, the loss of a competitor by itself does not lead to as large an increase in fares. In this situation, network and competition effects cancel, as can be seen in Table 7. Three of four individual fare changes, as well as both of the weighted-average changes, are insignificant in this case. When 3 or more airlines compete with the merging carriers in the market,

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[45]Since the model is estimated using coach-discount (YD) fares, these impacts only apply to this fare class (recall, however, that the YD class includes most of the DB1A data).

reduction of competition has virtually no effect on fares. In this case, network effects dominate and both of the weighted-average fare changes are significantly negative.[46]

These calculations show that competitive effects are strong relative to the network effects of a merger. However, since Table 7 shows that competition between the merging carriers occurs in relatively few markets, competitive effects play a minor role in determining the overall impact of each merger on 4-segment passengers. In the case of St. Louis, for example, markets served by TWA but not Ozark account for 59% of all markets served by one or both carriers, while markets served by Ozark but not TWA account for 31% of the total (the numbers in parentheses in Table 7 show the relative frequency of market types).[47] The balance of the markets (only 10%) have competition between TWA and Ozark (as seen in Table 7, 1% of the total have no other carriers aside from TWA and Ozark, 2% have one or two, and 7% have three or more additional carriers). Since the merger has no effect competition outside this small number of markets, network effects dominate in determining its overall impact. As a result, fares in the 4-segment markets fall on average in response to the merger, with the weighted average fare change across the

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[46]If the specification is modified to follow Morrison and Winston (1989), with extra competitors beyond one treated identically, then the simulation results are different. In this case MKTCOM23 and MKTCOM4+ are replaced by a single variable MKTCOM2+. Because MKTCOM2+'s coefficient is small in absolute value, fares fall in markets served by both TWA and Ozark and <u>at least one</u> additional carrier. Given that our MKTCOM coefficients are significantly different from one another (see footnote 40), Morrison and Winston's specification and the associated simulation results are inappropriate for our data.

[47]Since these numbers are based on the data used to construct network characteristics (DB1A records with 2 or more passengers), all actual service may not be captured.

different market types equal to -2.7% (this number is statistically significant).

A similar outcome emerges in the case of Minneapolis. Markets served by only one of the merger partners account for 82% of the total (20% of the markets are served by Northwest but not Republic, while 62% have Republic but not Northwest). With competitive effects present in only 18% of the markets (see Table 6 for details on their structure), network effects again dominate, reducing fares on average by a statistically-significant 1.2% across markets. This number is smaller than the St. Louis figure because the increase in network size is smaller for each Minneapolis carrier and because competitive effects are present in a greater share of the markets.[48]

7. Conclusion

This paper has provided the first detailed evidence linking airline fares to the structure of hub-and-spoke networks. Our results validate the basic hypothesis that forces leading to higher traffic densities on the spokes of a network reduce fares in the various markets it serves. This finding provides indirect evidence of the importance of networks in reducing airline costs.

The paper also sheds new light on the issue of hub concentration. Our findings show that a merger leading to a concentrated hub also generates an efficiency gain by creating a larger network. The simulation results suggest that in the 4-segment markets, where the merger has little effect on competition, this efficiency gain is passed on to passengers in the form of lower fares. This effect cushions the losses from higher fares paid by hub-originating and hub-terminating passengers, who may experience a significant reduction in competition as a result of the merger.

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[48] We are currently studying actual (as opposed to simulated) fare changes in the 4-segment markets served through St. Louis and Minneapolis.

Future research on network effects could take an approach less indirect than ours by studying the impact of network structure on actual traffic densities on the spoke routes. Since traffic and fares are jointly determined, however, such an investigation would require a structural model. In any case, given that hub-and-spoke networks will play a key role in airline operations for decades to come, further study of their impact deserves high priority.

Appendix

In performing two-stage least squares on the equation containing MKTCOM, we dropped the potential competition variable for reasons explained above, and added the following instruments to identify the equation: INCDEST, per capita income at the destination; CHINORIG, CHINDEST, percentage changes in per capita incomes at the origin and destination over the period 1979-1983; CHPORIG, CHPDEST, percentage changes in populations at the origin and destination over the period 1980-1986; HOTLDEST, HOTLORIG, hotel receipts as a fraction of total personal income at the origin and destination; CAPORIG, CAPDEST, dummy variables indicating whether the origin or destination is a state capital. The results of a two-stage least squares regression using these variables are reported in the second column of Table A1 (all the explanatory variables other than MKTCOM are exogenous). The estimates are computed using the entire data set. The first column of the Table reports OLS results for this specification.[49]

The OLS results are similar to the first-column results from Table 4, although the NTWAVGPP and NTWCOM4 coefficients are insignificant. Interestingly, the MKTCOM coefficient, which shows that addition of a competitor reduces fares by only 1.5%, dramatically understates the impact (from a better-specified equation) of adding the first few competitors to a monopolized market. The 2SLS results in column two are similar to the OLS estimates, but there are notable qualitative and quantitative differences.[50] Both the NTWAVGPP and MKTPP coefficients change sign from positive to negative, with the latter being significant (NTWAVGPP's coefficient remains

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[49]The coefficients for the slot-control and carrier dummies are not reported for either equation.

[50]It should be noted that a standard endogeneity test indicates that MKTPCOM is indeed endogenous.

insignificant). Some other coefficient magnitudes change dramatically, with MKTCOM's estimate indicating a stronger effect of competition (adding a competitor now reduces fares by 5.9%).

These results show that our main findings are reasonably robust to a crude simultaneity correction. Despite the poor performance of the population potential variables, the coefficients of NTWCITP4, ORIGSHR, and DESTSHR remain signficant and have magnitudes similar to their Table 1 values. The differences between the estimates and those in Table 4 may result from collapsing the separate market-competition variables into one, which leads to a misspecified equation.

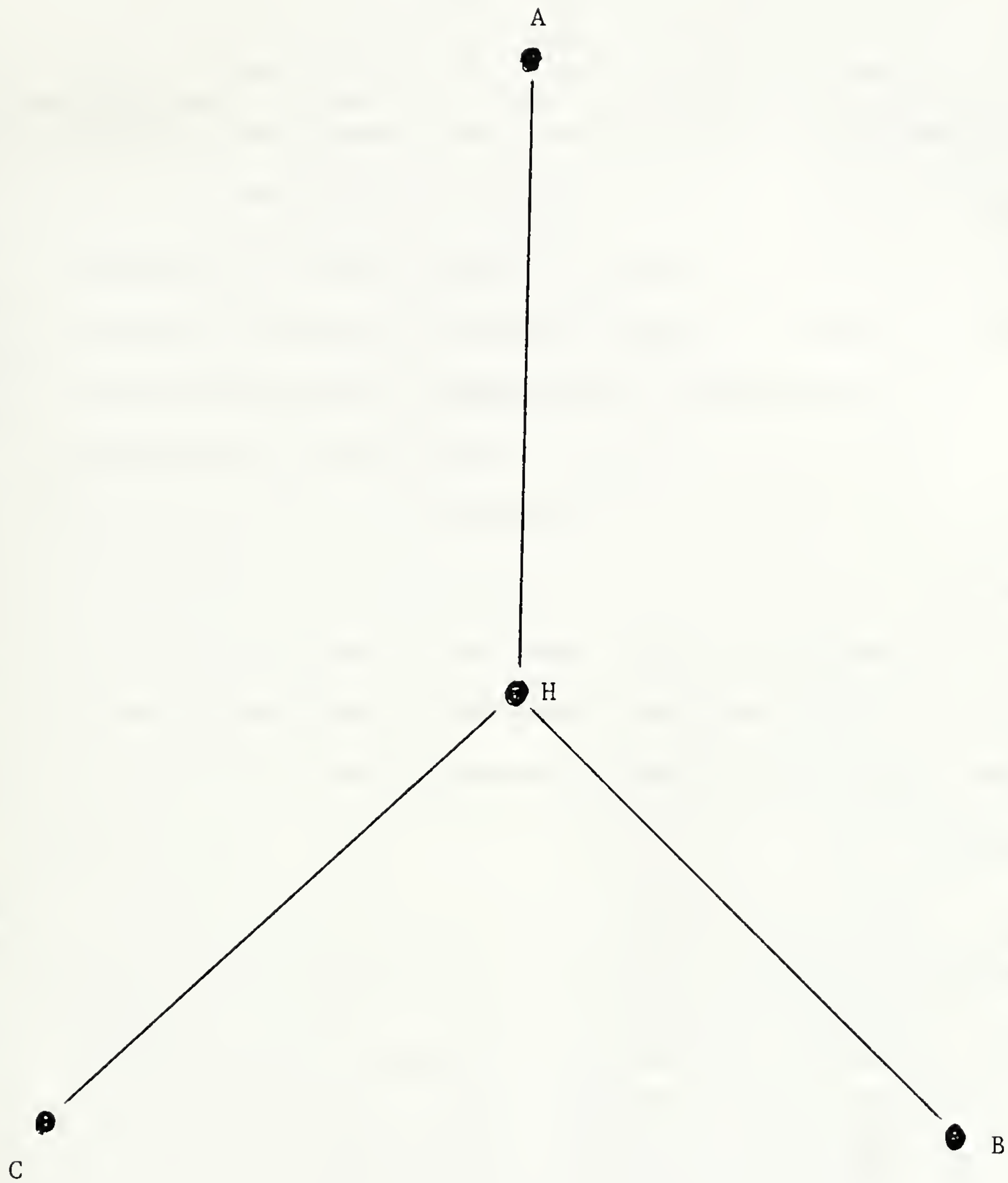

Figure 1.

Table 1

NETWORK CHARACTERISTICS (4th QUARTER 1985)

Hub/Carrier	NTWCITP4	POINTS	U4	U2	NTWCOM4	NTWCOM2	NTWCOM4S	NTWAVGPP
Atlanta/Delta	1368	86	.347	.884	.701	.921	.476	113.1
Atlanta/Eastern	1306	91	.319	.879	.779	.962	.498	131.5
Baltimore-Wash./Piedmont	214	47	.198	.787	.692	.568	.005	130.2
Charlotte/Piedmont	716	59	.418	.949	.588	.661	.053	127.4
Dayton/Piedmont	158	33	.299	.788	.665	.462	.000	135.4
Denver/Continental	307	44	.325	.886	.932	1.000	.554	204.4
Denver/Frontier	498	50	.407	1.000	.673	.900	.407	75.2
Denver/United	635	82	.191	1.000	.800	.927	.426	140.6
Dallas-Ft. Worth/American	1564	101	.310	.990	.650	.870	.227	134.7
Dallas-Ft. Worth/Delta	402	55	.271	.982	.948	.944	.868	152.4
Detroit/Republic	528	61	.289	.852	.642	.769	.013	156.2
Houston/Continental	325	44	.344	.909	.794	.950	.052	170.2
Kansas City/Eastern	125	39	.169	.949	1.000	.946	.064	291.1
Chicago (Midway)/Midway	64	19	.374	1.000	.984	.053	.000	252.7
Memphis/Republic	668	57	.419	.947	.704	.704	.058	134.2
Minneapolis/Northwest	242	42	.281	1.000	.740	.952	.368	183.4
Minneapolis/Republic	480	59	.281	.966	.429	.754	.185	81.7
Chicago (O'Hare)/American	758	78	.252	1.000	.815	.962	.506	174.1
Chicago (O'Hare)/United	1033	116	.155	.931	.754	.963	.372	151.4
Philadelphia/US Air	144	42	.167	.738	.507	.903	.000	113.0
Phoenix/America West	140	22	.606	1.000	.700	.682	.014	86.7
Pittsburgh/US Air	1243	81	.384	.914	.526	.568	.000	135.2
San Francisco/United	133	37	.200	.973	.398	.750	.030	97.7
Salt Lake City/Western	537	52	.405	1.000	.611	.692	.000	115.6
St. Louis/Ozark	445	54	.311	.926	.544	.800	.247	111.4
St. Louis/TWA	756	63	.387	.938	.952	.967	.146	196.0

Table 2

VARIABLE DEFINITIONS

NTWCITP4:	The number of 4-segment city-pair markets connected by the network
NTWAVGPP:	The average population potential of the network's 4-segment city-pair markets, where population potential equals the square root of the product of the market city populations
NTWCOM4:	The fraction of the network's 4-segment city-pair markets where at least one competitor is present
NTWCOM2:	The fraction of the network's 2-segment markets where at least one competitor is present
ORIGSHR:	The fraction of the network's 4-segment city-pair markets that include the origin city
DESTSHR:	The fraction of the network's 4-segment markets that include the destination city
DIST:	One-way flight distance for the market
MKTPP:	The market's population potential (see NTWAVGPP)
INCORIG:	Per capita income for the origin city
TEMPDIF:	The mean January temperature at the destination minus the mean temperature at the origin
MKTCOM:	The number of carriers competing with the given carrier in the market
MKTPCOM:	The number of carriers serving both endpoints of the market without serving the market itself
FARE:	The dollar fare
ORD, LGA, JFK, DCA:	Dummy variables taking the value one if origin or destination is one of the given airports
ORIGCONC:	A dummy variable taking the value one if the origin is a concentrated hub airport
DESTCONC:	A dummy variable taking the value one if the destination is a concentrated hub airport
POINTS:	The number of non-hub cities served by the network
U4:	The network's 4-segment utilization rate, equal to NTWCITP4 divided by POINTS*(POINTS-1)/2
U2:	The network's 2-segment utilization rate, equal to the number of 2-segment markets divided by POINTS
NTWCOM4S:	The fraction of the network's 4-segment markets with same-hub competition
NPASS:	Number of passengers on a record.

Table 3

SUMMARY STATISTICS

Variable	Mean	Minimum	Maximum
NTWCITP4	785	11	1564
NTWAVGPP	144.6	8.2	335.5
NTWCOM4	.706	.000	1.000
NTWCOM2	.813	.053	1.000
ORIGSHR	.053	.001	.385
DESTSHR	.052	.001	.385
DIST	1296	157	3471
MKTPP	167.3	2.0	1191.8
INCORIG	10160	5001	19411
TEMPDIF	3.8	-55.9	55.9
MKTCOM	3.39	0	22
MKTPCOM	2.32	0	11
NPASS	11.41	4	270
FARE*	269	34	1380

Dummy Means:

Carriers:		Other:	
US AIR	.082	ORD	.039
ASPEN	.002	LGA	.034
CONTINENTAL	.056	DCA	.040
DELTA	.005	JKF	.004
EASTERN	.100	ORIGCONC	.041
FRONTIER	.030	DESTCONC	.044
AMERICA WEST	.030		
MIDWAY	.014		
NORTHWEST	.017		
NEW YORK AIR	.001		
AIR CAL	.001		
OZARK	.017		
PIEDMONT	.105		
REPUBLIC	.102		
TRANS WORLD	.089		
UNITED	.094		
EMPIRE	.003		
WESTERN	.053		
FLORIDA EXPRESS	.008		
AIR WISCONSIN	.001		

*FARE's mean value is computed using all 9964 observations. Other means are computed from the mean-fare data set, where repeated itineraries are dropped (it has 6054 observations).

Table 4: REGRESSION RESULTS
(t-ratios in parenthesis)

Variable/Sample	ALL	ALL	MEAN-FARE	MEAN-FARE	ALL
INTERCEPT	3.005	2.920	3.124	3.039	3.008
	(33.36)	(32.53)	(29.27)	(28.51)	(33.40)
NTWCITP4	-0.0000489	-0.0000666	-0.0000238	-0.0000403	-0.0000495
	(3.08)	(4.22)	(1.25)	(2.13)	(3.12)
NTWAVGPP	-0.000460	-0.000482	0.00000463	-0.0000113	-0.000466
	(2.47)	(2.58)	(0.02)	(0.05)	(2.50)
NTWCOM4	0.191	0.188	0.134	0.129	0.192
	(3.31)	(3.25)	(1.95)	(1.87)	(3.32)
NTWCOM2	0.015	0.00663	0.112	0.0941	0.0145
	(0.24)	(0.11)	(1.47)	(1.23)	(0.24)
ORIGSHR	-0.854	-0.925	-0.887	-0.964	-0.861
	(7.10)	(7.68)	(6.29)	(6.82)	(7.14)
DESTSHR	-0.929	-0.996	-1.034	-1.108	-0.921
	(7.57)	(8.10)	(7.18)	(7.68)	(7.50)
LDIST	0.373	0.390	0.337	0.356	0.373
	(47.93)	(51.98)	(37.22)	(40.68)	(47.93)
MKTPP	-0.0000625	-0.000101	-0.0000466	-0.0000934	-0.0000651
	(2.06)	(3.38)	(1.29)	(2.62)	(2.15)
INCORIG	0.00000994	0.00000831	0.0000111	0.00000927	0.00000978
	(3.67)	(3.06)	(3.51)	(2.92)	(3.60)
TEMPDIF	-0.000818	-0.000825	-0.000894	-0.000912	-0.000794
	(5.98)	(6.01)	(5.47)	(5.56)	(5.79)
MKTCOM1	-0.0766	-0.0844	-0.0708	-0.0798	-0.0764
	(7.75)	(8.56)	(6.23)	(7.03)	(7.74)
MKTCOM23	-0.0344	-0.0405	-0.0414	-0.0482	-0.0341
	(7.19)	(8.53)	(7.22)	(8.47)	(7.14)
MKTCOM4+	-0.00625	-0.00524	-0.00585	-0.00456	-0.00622
	(4.30)	(3.60)	(3.23)	(2.52)	(4.27)
MKTPCOM	-0.0156	**	-0.0172	**	-0.0157
	(8.17)		(7.47)		(8.22)
ORIGCONC	**	**	**	**	-0.0158
					(1.06)
DESTCONC	**	**	**	**	0.0370
					(2.45)
R^2	.3610	.3567	.3838	.3781	.3615

Table 5

AIRPORT AND CARRIER DUMMY COEFFICIENTS

(Estimates are for first equation of Table 4;
t-ratios in parentheses)

ORD	0.0466 (2.95)	MIDWAY	-0.0611 (0.96)
LGA	0.00214 (0.13)	NORTHWEST	0.0454 (1.68)
JFK	-0.654 (1.13)	NEW YORK AIR	0.0201 (1.52)
DCA	0.0978 (6.73)	AIR CAL	-0.0163 (0.12)
US AIR	0.00907 (0.40)	OZARK	-0.0372 (1.16)
ASPEN	0.252 (2.83)	PIEDMONT	-0.0657 (2.71)
CONTINENTAL	-0.0994 (4.79)	REPUBLIC	0.0296 (1.48)
DELTA	0.146 (2.88)	TRANS WORLD	0.00370 (0.24)
EASTERN	0.0531 (4.07)	UNITED	0.0802 (5.48)
FRONTIER	-0.0918 (3.23)	EMPIRE	0.124 (5.25)
AMERICA WEST	-0.106 (3.39)	FLORIDA EXPRESS	0.118 (3.47)
		AIR WISCONSIN	0.638 (5.84)

Table 6

IMPACTS OF VARIABLES ON FARES

Variable change	Percentage Change in Fare
Network 4-segment city-pairs increases by 100	-0.5%
Network average population potential increeses by 41 (one std. dev.)	-1.9%
Fraction of network 4-segment markets with competition increases by .15 (one std. dev.)	+2.9%
Fraction of network 4-segment markets that include origin increases by .04 (one std. dev.)	-3.4%
Fraction of network 4-segment markets that include destination increases by .04 (one std. dev.)	-3.7%
Distance increases by 1%	+0.4%
Market population potential increases by 143 (one std. dev.)	-0.9%
Per capita income of origin city increases by 1210 (one std. dev.)	+1.2%
January temperature differential increases by 22 degrees (one std. dev.)	-1.8%
Number of market competitors increases from zero to one	-7.7%
Number of market competitors increases from one to two or from two to three	-3.4%
Number of market competitors increases from three to four	-0.6%
Number of potential competitors increases by one	-1.6%
Origin or destination is Chicago-O'Hare	+4.7%
Origin or destination is Washington-National	+9.8%

Table 7

Merger Simulations

Pre-Merger Carrier/Hub	Change in: NTWCITP4	NTWAVGPP	NTWCOM4
TWA/St. Louis	+532	-34.9	-.143
Ozark/St. Louis	+843	+49.7	+.265
Northwest/Minneapolis	+557	-84.1	-.247
Republic/Minneapolis	+319	+17.6	+.064

ST. LOUIS NETWORK FARE CHANGES:

Fare changes on original TWA routes under different competitive conditions:

TWA without Ozark (.59):	-3.7%*
TWA and Ozark with no competitors:	+3.9%*
TWA and Ozark with 1 or 2 competitors:	-0.3%
TWA and Ozark with 3 or more competitors:	-3.1%*

Fare changes on original Ozark routes under different competitive conditions:

Ozark without TWA (.31):	-1.3%
Ozark and TWA with no competitors:	+6.3%*
Ozark and TWA with 1 or 2 competitors:	+2.1%
Ozark and TWA with 3 or more competitors:	-0.7%*

Weighted average fare changes on routes served by both TWA and Ozark

TWA and Ozark with no competitors (.01):	+4.7%*
TWA and Ozark with 1 or 2 competitors (.02):	+0.5%
TWA and Ozark with 3 or more competitors (.07):	-2.3%*

* - fare change significantly different from zero at the 5% level

Numbers in parentheses give relative frequency of each type of market

Table 7 continued

MINNEAPOLIS NETWORK FARE CHANGES:

Fare changes on original Northwest routes under different competitive conditions:

Northwest without Republic (.20):	-3.6%*
Northwest and Republic with no competitors:	+4.1%*
Northwest and Republic with 1 or 2 competitors:	-0.1%
Northwest and Republic with 3 or more competitors:	-3.0%*

Fare changes on original Republic routes under different competitive conditions:

Republic without Northwest (.62):	-1.1%**
Republic and Northwest with no competitors:	+6.5%*
Republic and Northwest with 1 or 2 competitors:	+2.3%*
Republic and Northwest with 3 of more competitors:	-0.5%

Weighted average fare changes on routes served by both Northwest and Ozark

Northwest and Republic with no competitors (.06):	+5.2%*
Northwest and Republic with 1 or 2 competitors (.03):	+1.0%
Northwest and Republic with 3 or more competitors (.09):	-1.8%*

* - fare change significantly different from zero at the 5% level

** - fare change significantly different from zero at the 10% level

Numbers in parentheses give relative frequency of each type of market

Table A1

Two-Stage Least Squares Results

(Based on entire sample; t-ratios in parentheses)

Variable	OLS	2SLS
INTERCEPT	2.954	2.214
	(32.75)	(17.74)
NTWCITP4	-0.0000737	-0.0000712
	(4.63)	(4.19)
NTWAVGPP	-0.000259	0.000246
	(1.38)	(1.18)
NTWCOM4	0.0834	0.135
	(1.44)	(2.17)
NTWCOM2	0.00415	0.0933
	(0.07)	(1.41)
ORIGSHR	-0.946	-0.996
	(7.79)	(7.68)
DESTSHR	-0.990	-0.963
	(7.98)	(7.27)
LDIST	0.385	0.457
	(51.01)	(40.96)
MKTPP	-0.0000884	0.000465
	(2.93)	(6.88)
INCORIG	0.00000551	0.0000143
	(2.02)	(4.68)
TEMPDIF	-0.000862	-0.000475
	(6.22)	(3.09)
MKTCOM	-0.0149	-0.0592
	(12.51)	(12.04)
R^2	.3446	**

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